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Frédéric SEGONDS, Julien NELSON, Améziane AOUSSAT - PLM and architectural rehabilitation : a framework to improve collaboration in the early stages of design - 2012

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PLM and architectural rehabilitation: a framework to improve collaboration in the early stages of design

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Abstract: Recent evolutions in French law regarding accessibility of public buildings have prompted a need for methods and tools to rehabilitate such structures in order to make them accessible to disabled users. Architectural rehabilitation is an exceedingly complex design process, in particular, because of a legal framework which strongly impacts on the structure of collaboration, and of the need to take into account the characteristics of existing buildings. In this paper, we describe a participatory design methodology applied in the rehabilitation of a School of Engineering in France in order to improve its accessibility, and describe the basic functionalities of a software tool to assist collaborative engineering in architectural redesign projects.

Keywords: product lifecycle management; PLM; building rehabilitation; accessibility; disabled users.

Reference to this paper should be made as follows: Segonds, F., Nelson, J. and Aoussat, A. (2012) 'PLM and architectural rehabilitation: a framework to improve collaboration in the early stages of design', *Int. J. Product Lifecycle Management*, Vol. 6, No. 1, pp.1–19.

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1 Introduction

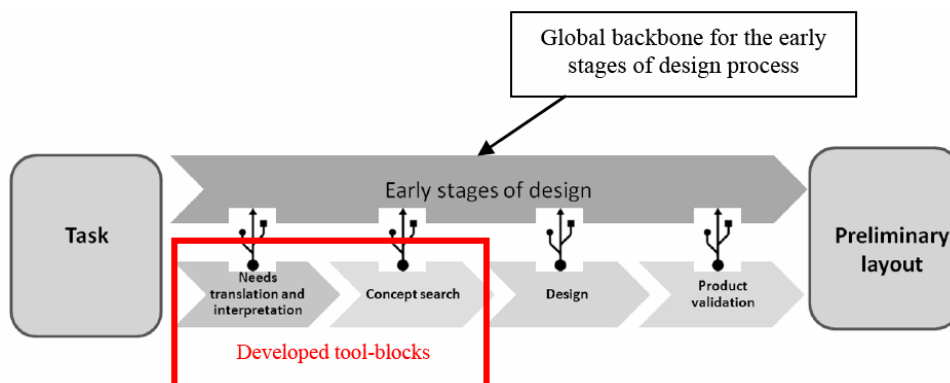
In France, the ‘February 11th, 2005’ Law, named after its date of enactment, stresses the need for equal rights, opportunities, and participation to citizenship for all disabled persons (Winance et al., 2007). This law introduced a general principle of accessibility in French society, pertaining to many aspects of public life: sustained employment, urban travel, accessibility of public buildings, etc. Regarding the latter, the law states that “architectural buildings, structures and equipment located both inside and outside of residential premises, whether they be public or private property, establishments of public accommodation, locations open to the public or workplaces must be accessible to all and notably to disabled persons whatever the nature of their disability, notably physical, sensory, cognitive, mental, or psychical”.

Despite the fact that the law has prompted much work to rehabilitate existing public premises, there exists at the time of writing no clear methodology, and few design criteria, to assist the rehabilitation of buildings in order to improve their accessibility to the disabled. The key goals of this paper are (Figure 1):

- to define the backbone of a tool intended to assist the early stages of design, in the case of architectural rehabilitation, and its integration with existing tools
- to describe the two first tool-blocks of our model, using a simple computer-aided design (CAD) representation and an annotation tool.

We first define architectural rehabilitation as a design process affected by specific, contextual constraints. We then describe some difficulties related to integrating data related to users, in particular to disabled users, in this design process, from a collaborative engineering (CE) point of view. In the third part, we propose that product lifecycle management (PLM) methods and tools may assist CE in architectural rehabilitation. Finally, we describe a software platform under current development, aiming to assist CE in a PLM framework, and describe a case study: the rehabilitation of a School of Engineering in France. We conclude the paper with some prospects for future research and for the development of this tool.

Figure 1 Framework describing the early stages of design process (see online version for colours)



Source: From Segonds et al. (2009)

2 Architectural rehabilitation as a constrained design process

Design science has a somewhat ambiguous relationship with architectural design, viewing it both as one instance of a *generic* activity and as a *specific* practice or form of design (Visser, 2009). The first view derives from Simon's (1969) view that architecture is a typical example of a design activity which he classifies as solving an 'ill-structured' problem, i.e., where the problem's start-state, goal-state, and/or available operators are not known in advance. Designer activity involves gradually defining this problem space. From a project-based view, this implies that as time progresses, designers' freedom to make decisions reduces as the accumulated information about future building specifications increases (Midler, 1995). Furthermore, many authors have argued that this collaborative work is guided by various artefacts, such as sketches or plans, alternately termed intermediary objects, boundary objects, or intermediate representations (IRs) (e.g., Boujut and Blanco, 2003; Bouchard et al., 2005). Such artefacts are a means to generate design alternatives and consensus between the stakeholders involved. The second view describes architecture as a specific practice, and strives to understand architects' specific expertise in the task of designing buildings (Akin, 1986). Without denying the importance of the first strand of research, our work is based on the second approach.

More specifically, we are concerned with tasks of architectural rehabilitation or redesign. These can be viewed as a means to ensure that an existing building continues to generate value to its users for as long as possible instead of having to undergo a costly process of demolition and reconstruction (Lindekens et al., 2003). These authors point out such projects take place in an 'enlarged context' taking into account the building's history, physical properties, structural characteristics, etc. In other words, architects must manage the constraints that come with the project, comprising both a partial description of the characteristics of the solution (Stefik, 1981), and the constraints related to project operation, e.g., time or cost limitations.

3 Integrating use-related data in architectural rehabilitation

3.1 Decision-making in the architectural design process: the French context

Although some authors have highlighted the need to provide architects with data regarding future users and their activities to assist user-centred architectural design, one can point out that the complex planning process involved both in architectural design and redesign can make this a very complex task. An extensive survey has been carried out, describing the sources of this complexity in the French social and legal context of public architectural contracting (Martin, 1998). These issues derive mainly from a legal framework defining two separate actors:

- a the *client*, i.e., the entity for whom the architectural project is being undertaken
- b the *contractor*, i.e., the entity in charge of carrying out design and supervising construction work, for example, a team of architects, structural engineers, etc.

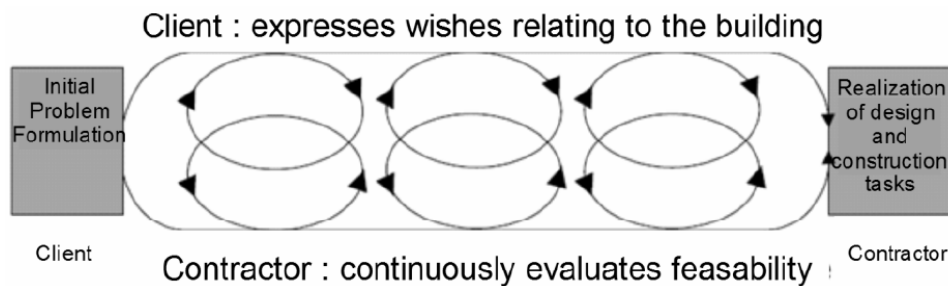
Communication between the two is ensured through the production of an intermediary object termed the ‘architectural programme’, broadly defining the intended characteristics of the building from the client’s point of view.

The key issue in this collaborative setup is that, whereas the contractor typically has some experience in architectural design, the client has none. There is therefore a gap, in these situations, between design on the one hand, and decision-making on the other. Design can only progress if some sort of consensus is reached between project stakeholders. Consequently, the entire design process involves many design meetings where various alternatives are weighed in terms of their *pros* and *cons*. These discussions focus on user needs, on design concepts, and on their materialisation in detailed design.

To counter these issues, Martin (1998) proposed a model of user-centred architectural design (Figure 2) based on the following principles:

- 1 A clear identification of the actual stakeholders behind the ‘client’ entity and a focus of design on the analysis of situations deemed characteristic of future building use (Daniellou, 2007).
- 2 A good knowledge of the contractor’s data requirements for redesign: when and in what form should they be provided?
- 3 A strict compliance with participatory design principles, i.e., direct involvement of users in the design process.
- 4 Providing means for continuous client-contractor interactions throughout the project.

Figure 2 Model of client-contractor interactions in architectural design



Source: From Martin (1998)

These principles hold true in the case of architectural redesign, but are all the more important that such projects are associated with more stringent constraints. Time and cost constraints (Savage et al., 1998) are usually more intense, since design and construction need to be balanced against the requirements of continued building operation. Consequently, redesign projects often last several years and are often spread out over a series of minor alterations rather than one major ‘makeover’. However, these principles only provide a general framework for user-centred architectural redesign, whereas redesigning buildings to be accessible to disabled persons poses specific issues. To present our approach, which focuses on the accessibility of buildings to the disabled, we first need to clarify the interrelations between the concepts of disability, accessibility, and user-centred design (UCD).

3.2 Designing buildings for improved accessibility to the disabled

The definition of disability has undergone major evolutions in recent years, mirroring evolutions in its recognition by the welfare system. The previously dominant, medical approach of disability, based on its definition as a physical abnormality, has gradually been displaced by a social-centric view where disability is produced by the interaction of individual limitations with environmental determinants, hindering participation to social life (Fougeyrollas, 1995). The definition chosen by the World Health Organization (WHO) bridges these two views by distinguishing three related concepts (Mitra, 2006): *impairment* refers to a problem in body function or structure; *activity limitation*, to a difficulty encountered by an individual in executing a task or action; and *participation restriction*, to a problem experienced by an individual in his/her involvement in life situations. Disability refers to all three levels of this continuum. Several scholars, however, have criticised the WHO definition as being overly materialistic (Burchardt, 2004; Terzi, 2004; Mitra, 2006). Instead, they propose an approach based on the concepts of capabilities (Sen, 1999) and focusing on providing users with opportunities for personal development. Sen's framework distinguishes two key concepts: *functioning*, i.e., the activities a person carries out, and *capabilities*, i.e., the practical opportunities available to the individual to achieve a given functioning. In this framework, disability can be understood as a deprivation of a set of capabilities as a result of an impairment, with a variable impact on the functioning level. Disability, therefore, arises from several factors: the impairment, the resources available to the individual, and the environment (Mitra, 2006). Accessibility, therefore, is a means to provide users of a building with opportunities to carry out activities within this building. These activities are supported by a number of structures within the building, which define its intended use (Winner, 1986; Nelson et al., 2009) – some of them explicitly, e.g., a lecture hall intended to house lessons, and some less so, e.g., 'gathering areas' to be dotted all around the building.

UCD of public buildings thus rests on taking into account the characteristics of user activity within the building in order to identify means to efficiently restore user capabilities for action. Theories of human activity have evolved in recent years, generally highlighting their situated nature (Béguin and Clot, 2004; Suchman, 2007). As Suchman writes, "Every course of action depends in essential ways upon its material and social circumstances". To structure their understanding of this enormous variability, designers frequently rely on specific devices.

First, at the micro level, *scenarios* are used as narrative descriptions of specific situations of use to ensure user-centredness in the design process. These also assist decision-making by helping designers 'make claims' (Carroll and Rosson, 1992) regarding the relationships between:

- 1 building characteristics and limitations of user capabilities
- 2 restoration of these capabilities through alterations in building design.

Second, at the macro level, design decisions can be evaluated based on iterative simulations of user behaviour. Although the traditional approach of iterative prototyping and user testing is mostly impractical in architectural design, it is certainly a viable tool for redesign since an actual structure is available within which one can analyse user

activity in specific situations. Designers then construct and evaluate situations which are representative of future use by browsing ‘situation libraries’ (Daniellou, 2007).

In both cases, the designer is still dependent upon single situations as a unit of analysis. To us, a major consequence of this is that user centred design fails to take into account the dual complexity of the building’s lifecycle: on the one hand, contextual characteristics are liable to restrict users’ capabilities regarding some aspects of building use, e.g., when certain areas of the building are isolated for maintenance; on the other, the constraints surrounding architectural redesign (see above) cast some uncertainty as to how long such limitations are to last. For both these reasons, we posit that implementing a PLM tool might provide useful assistance to architectural redesign.

4 PLM as a tool for CE in architectural redesign

4.1 Rationale for PLM in architectural design

In the early 2000s, PLM emerged as a solution to adapt industrial design to the demands of globalisation. Indeed, as PLM addresses the entire lifecycle of the product, it has a cross-functional nature and is closely suited to the way a company operates (Garetti et al., 2005). Collaborative design has been the subject of numerous studies. With the development of product data management (PDM), PLM and associated workflows, software firms have proposed solutions to the everyday problems of engineering design departments (e.g., versioning, naming documents, etc.). PLM aims to cover all stages of product development by integrating the processes and people taking part in the project (Schuh et al., 2008). This concept is generally used for industrial products. For Amann (2002), over the past several years, PLM has emerged as a term to describe a business approach to the creation, management, and use of product-associated intellectual capital and information throughout the product lifecycle. Thus, PLM is an approach in which processes are just as important as data, maybe even more so. The PLM approach can be viewed as a trend toward the complete integration of all software tools taking part in design and operational activities during a product lifecycle (Garetti et al., 2005; Donati et al., 2010). Therefore, PLM software packages need PDM systems; synchronous and asynchronous, local and remote collaboration tools; and if necessary, a digital infrastructure allowing exchanges between software programmes (Segonds et al., 2011).

PLM is thus a design framework which aims to cover all stages of product development through integration of all processes and actors involved in the project (Saaksvuori and Immonen, 2008). In the building industry, recent studies have proved that a major cause of failure in building and construction is the use of invalid or erroneous documents/models during the process (Reefman and Van Nederveen, 2011). Therefore, a PLM platform is expected to bring many advantages to structuring collaboration between numerous stakeholders in the complex framework of an architectural design project. However, although PLM is widely used in designing mechanical or engineering products, a building presents designers with an entirely different set of issues. Fewer solutions are available to help the stakeholders of an architectural design project represent the entire lifecycle of a *building*, and store the IRs and data which are necessary for successful collaboration (Bouchard et al., 2005).

4.2 *Integrating evolutions in time: a specific requirement in architectural design projects*

In a product design project, the data (naming, versioning...) relates to a product. In architectural design, it relates to a building, which can evolve suddenly for no foreseeable reason (e.g., an explosion, an internal reorganisation, etc.). Although lightweight representations can be used in both cases, a crucial point to be made here is that buildings represent a special kind of artefact, which is meant to evolve through time.

Thus, Dudek and Blaise (2008) strongly distinguish the *evolution* of an artefact from its *lifecycle*. The first is defined as “the time slot between its creation and its extinction”. The artefact’s lifecycle, in contrast, identifies a “time slot corresponding to a consistent physical continuum, during which transformations are partial”. The evolution of a building (e.g., a School of Engineering) may thus pass through several lifecycles, which is very unusual for a product. In the case of rehabilitating a School of Engineering through architectural redesign, the alterations made to improve the accessibility of a lecture hall relate to the lifecycle, whereas rebuilding the whole workshop area is an evolution, and implies a new lifecycle for this particular feature. Each lifecycle of the building thus refers to a set of discrete states, with no major transformations; and transitions, during which transformations occur. To represent these, Dudek and Blaise (2008) suggest using “diagrams that act as visual explanations of the artifact’s lifecycle”. The tool we present in Section 4.3 includes diagrams that present the evolution of the artefact along a time axis (see Figure 7).

The promise behind PLM in architectural redesign, therefore, lies in the seamless integration of “*all* the information produced throughout *all* phases of a product’s lifecycle to *everyone* in an organisation, along with key suppliers and customers” (Sudarsan et al., 2008).

4.3 *Our proposal: a tool to track design changes and alternatives to assist decision-making*

CE tools used in architectural design should provide designers with temporally-ordered IRs of the building. It should also store design recommendations and design alternatives, so that each stakeholder might understand the building’s evolutions – and more importantly, keep track of existing flaws and assess the relevance of design concepts proposed to solve them. To this end, we used ‘history graphs’ (Renolen, 1996). These describe an artefact’s history through a series of consecutive versions and transitions, characterised by a time interval. Other descriptive frameworks of architectural changes have been developed, especially in the field of heritage architecture.

Our approach is further motivated by two points: first, in spite of the fact that product design and architectural design refer to very different practices, recent work has attempted to apply models, methods and tools of industrial design to address the unmet needs of architects. Second, major rehabilitation projects lasting several years involve handling large numbers of IRs and accessing information generated at any time during the building’s lifespan, which typically lasts decades or even centuries.

Following this, we defend Martin’s (1998) view that client/contractor interactions in architectural redesign need to be better organised to endure greater user-centredness. Ergonomist involvement is not sufficient to ensure this: one must also ensure that the relevant user-centric data and representations are available to stakeholders at the right

time. Ding et al. (2009) stress that multiple viewpoints in the design process cause increased processing times and storage needs, and that annotated lightweight representations are needed to facilitate communication and the storage of project-related data. Using such representations, a client or contractor might extract information at any time, regarding ongoing and upcoming projects and events involving the building, to better plan the design and construction work, and to make decisions based on multiple points of view. In particular, annotation offers the possibility to explicitly state and debate (e.g., in a participatory design team) possible alterations to the building and their expected effects on user activity and capabilities. Geryville et al. (2006) also point out that multidisciplinary collaboration allows stakeholders to express their interests regarding future user activity, by using a variety of representations. The aim of PLM as a tool for CE in architectural design is to provide, in the case of the rehabilitation of public buildings, these representations and to facilitate their extraction. Such representations must also be congruent with practices in architectural design. For this reason, we posit that a PLM tool for architectural design should strongly take into account the main type of PDM tool used in this field, namely building information modelling (BIM) tools.

4.4 *PLM and BIM*

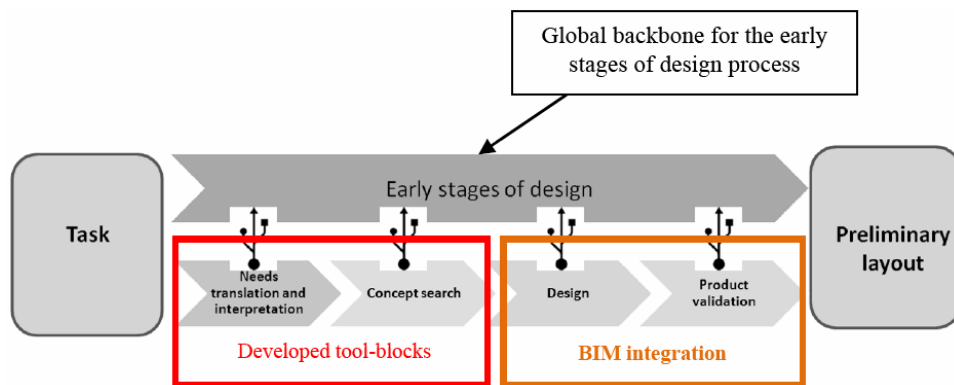
Several authors (e.g., Grilo and Jardim-Goncalves, 2010) have shown that despite the widespread use of 3D CAD software in architectural design and redesign, the dominant format for collaborative work and communication in the early stages of the process is 2D-based. Depending on the stage of the project, design decisions may be embodied in sketches, floor plans in various levels of detail, etc. 3D representations are used more intermittently, to illustrate design decisions in conjunction with 2D models and other documents. The recognition of the need to provide stakeholders with richer information in the design process is the main rationale behind BIM, which uses object-oriented programming to facilitate interoperability between the design and construction stages (Eastman et al., 2003). The first report of the potential of BIM to transform processes in the architecture, engineering and construction (AEC) industry emerged in the late 1980s and early 1990s (Linderoth, 2010). Manning and Messner (2008) have noted several benefits of using BIM in the conceptual stage of design. Such benefits include rapid visualisation and improved decision support in the development process. However, with respect to Section 2, several points must be made:

- BIM software clearly complements the PLM framework. But it focuses mainly on bridging the information gap between design and product validation before construction (see Figure 3), not on the UCD of buildings, although recent work has begun to address this concern (Van Nederveen and Gielingh, 2008).
- Some BIM standards have been developed. For example, the National BIM standard approach is well suited to the construction of new buildings. It uses groups of experts in AEC to specify use-cases in what they call ‘information delivery manuals’ (IDMs). These IDMs serve as a basis to create specific import and export translators to facilitate collaboration between design and construction stakeholders (Eastman et al., 2010).

- Assisting the redesign of existing buildings, especially to the degree of France at the time of writing, is less of a concern to BIM than assisting the design of new buildings, allowing leeway for redesign later in the lifecycle.
- More importantly to us, BIM software is currently incompatible with design approaches placing user involvement at their core such as participatory design, and is therefore of limited interest to user-centred architectural redesign.

Since BIM helps to efficiently manage the collaborative exchange of information in building design and construction, the position of our work is to define a global framework to assist stakeholders in the early stages of design towards efficient architectural rehabilitation, taking into account issues of accessibility. This framework has been developed through a methodology aiming to develop a tool for designers. As we point out below, a tool for CE in architectural design should be a synthesis between existing methodologies and user-centred approaches, from the early stages of design onwards. We now present the results obtained by using this tool, and define its structure and functionalities.

Figure 3 A model of the early stages of design, the position of our work and integration of BIM tools (see online version for colours)



Source: Adapted from Segonds et al. (2009)

5 Results

5.1 A model of the early stages of architectural redesign

Segonds et al. (2009) have compared several models of the engineering design process to propose a descriptive framework of the 'early stages' of design, as well as a model for collaborative work in these stages. This model, although it is based on models of product design, lends itself well to the early stages of architectural design (see Figure 3).

This model is aimed to help the client debate design alternatives for building rehabilitation with the various stakeholders, especially with contractors. It is strongly influenced by the work of Aoussat et al. (2000) in the following respects:

- *Emphasis on the multidisciplinary nature of design work:* each stage involves professionals from various fields who should be able to ‘plug in’ to the system to access relevant information to the tasks performed by them in any given stage.
- Redesign work, ranging from the reception of the programme by the architect, to the elaboration of definitive floor plans, comprises four stages:
 - 1 *Translation and interpretation of client needs:* these are embodied in the programme. The client may rely on an ergonomist at this stage to ensure user-centredness throughout the redesign process. The principles of his/her intervention are outlined in Section 2. Observation of current building use aims to identify accessibility issues, which are not restricted to disabled users. Observation results are reported in annotations made on lightweight 3D representations of locations within the building. This allows designers to gain a clear picture of the ways in which current building characteristics restrict user capabilities for action.
 - 2 *Concept search:* this is carried out by the architectural firms as a response to the programme. The client must then evaluate concepts presented to him by a number of design firms to choose the most viable one. Here, similar IRs allow the client to ‘walk through’ various usability issues when carrying out this evaluation in order to choose the most user-friendly redesign concept.
 - 3 *Design:* it relies on producing a number of deliverables describing the redesigned building in increasing detail. Likewise, the focus on accessibility issues will be more specific. For example, whereas concept search may strive to find ways for wheelchair-bound users to access the main structures of the building, later stages might focus on the dimensions of the corridors spanning the paths defined earlier.
 - 4 *Product validation:* this is a more complex issue than in the case of product design, where iterative prototyping and evaluation are commonplace. Validation can take place using ‘floor plan’ IRs or scale models for designers and end users to walk through.

During the two latter steps, most of the data generated can be managed using BIM software. Our framework aims to extract IRs from this data to implement as the backbone of our tool. The rationale behind a tool to assist UCD stems from the knowledge that integration of user-related data in the redesign process is a complex issue (see Section 2) and that this state of affairs is an obstacle for contractors and clients to access key user-centric data and formulate a plan to manage the constraints of redesign and construction. For these reasons, UCD applied to architectural rehabilitation has to be structured using a dedicated tool.

5.2 *A tool to structure UCD in these early stages*

The project upon which this case study is based involves the redesign of a School of Engineering in Paris to ensure its compliance with the disability law within the legal deadline (five years following the inception of the law). The school has a diverse population of everyday users numbering approximately as follows: 1,400 students and 200 teaching and administrative staff.

Ergonomics involvement was requested in the needs translation stage of this redesign process. It was based on the model presented in the section above. Its main stages were as follows:










- Initial interactions with the client (the head of the school board) and with user advocates (14 people, members of an association representing disabled staff and students of the school) allowed the ergonomist to gain an overall picture of the activities performed within the school, pertaining to all of its missions: teaching, research, and industrial work. Interviews with these stakeholders focused on activities which were *characteristic*, both of the nominal operation of the school (e.g., ‘Tell me about your typical day at the school’) and of incidental situations (e.g., ‘Can you tell me about any major events, either in the recent past or in the near future, where accessibility was or might be an issue?’).
- These activities were translated to sets of possible access paths using a method similar to a cognitive walkthrough (Lewis et al., 1990). This allowed the design team to identify a list of relevant locations within the school for finer examination: schoolrooms, restaurant, etc. Our unit of analysis was typically a room within the school, as well as the access routes allowing users of the building to access this room. In other words, drawing again on the analogy with product design, we focus on the *portion* level, being defined as a subset of an artefact (Dudek and Blaise, 2008).
- Capability limitations are then imported within a matrix (Figure 4) whose columns correspond to various types of impairment retained for examination in the scope of this design project (motor, visual, and hearing impairments) and whose rows refer to key tasks defined jointly by the client and users involved in the process. This allowed us to highlight key priorities for the ‘functioning’ of users in their activities:
 - 1 entering/exiting the area
 - 2 acting within the area, i.e., carrying out the tasks for which the area is intended (e.g., attending a course, having a meal, etc.)
 - 3 evacuating the area, i.e., being able to access an exit path under degraded conditions.

Debate in a participatory design team helped us prioritise redesign work to restore user capabilities.

- Needs translation and interpretation relies on simple CAD models using sketchup to illustrate before/after states of the building and the expected effects on accessibility, for the different disabilities highlighted in the matrix.

In the near future, these CAD models will be implemented in a CE tool, and all the stakeholders of the architectural redesign project will be able to access and comment on the decisions made. In the next section, we present the overall user interface of the software redesign tool, and its main functionalities.

Figure 4 Capability matrix for the use of a lecture hall (see online version for colours)

	<i>Motor</i>	<i>Visual</i>	<i>Hearing</i>
Enter/exit			
Act			
Evacuate			

Note: Double-crossed pictures indicate serious capability limitations, single-crossed picture less serious limitations, and uncrossed pictures, the relative absence of limitations.

5.3 Development of a tool to assist collaboration in early design stages

We believe the complexity of the architectural redesign process justifies the need for a new tool to manage the building lifecycle, albeit with a stronger focus on UCD than existing (BIM) software. Our tool is specifically geared to assist cognitive synchronisation, assessment of solutions, and proposing solutions (Détienne et al., 2004) in the early stages of architectural rehabilitation. Thanks to this software, many stakeholders will be able to access building-related information stored in a database. This tool prototype relies first and foremost on capitalising the data generated by the design team in the early stages of redesign, including – but not limited to – data pertaining to user-centred aspects of design. For example, Figure 5 shows the possibility to report the results of user observations in annotations made on lightweight representations of key locations within the building. This can, in turn, help the client better specify the architectural programme.

Following the model of early stages of design in Figure 3, each stakeholder might ‘plug in’ to the software to consult data relevant to his own design expertise and project duties. In particular, design alternatives could be reviewed based on the exchange of multiple annotated IRs (see Figure 6).

Figure 7 describes a screen mockup from this proposed software suite. The top area allows users to log in to four modules that can be plugged from the early stages of rehabilitation. The ‘needs’ thumbnail (leading to Figure 5) allows the client to specify current functioning limitations for users due to building characteristics, using 3D CAD models, and an annotation tool to highlight accessibility issues. The ‘concepts’ thumbnail (leading to Figure 6) allows contractors to propose different solutions to cope with an accessibility limitation, to import CAD-generated alternatives for redesign, and to broadcast documents to members of the design team that are relevant to their respective expertise.

Figure 5 Capability limitations and underlying causes in a lecture hall (see online version for colours)

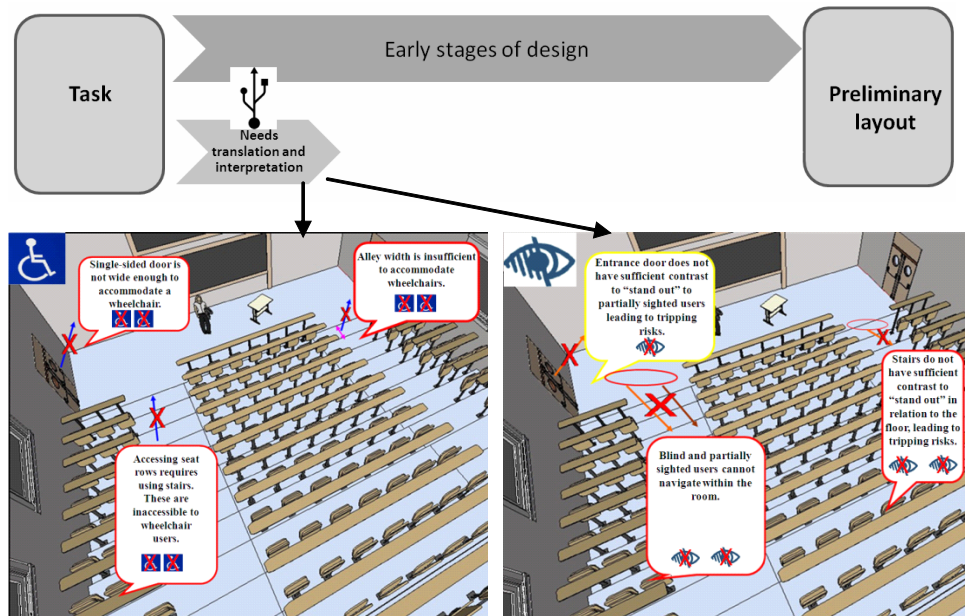


Figure 6 Putative redesign concepts to restore capabilities in users with (a) motor and (b) visual impairment (see online version for colours)

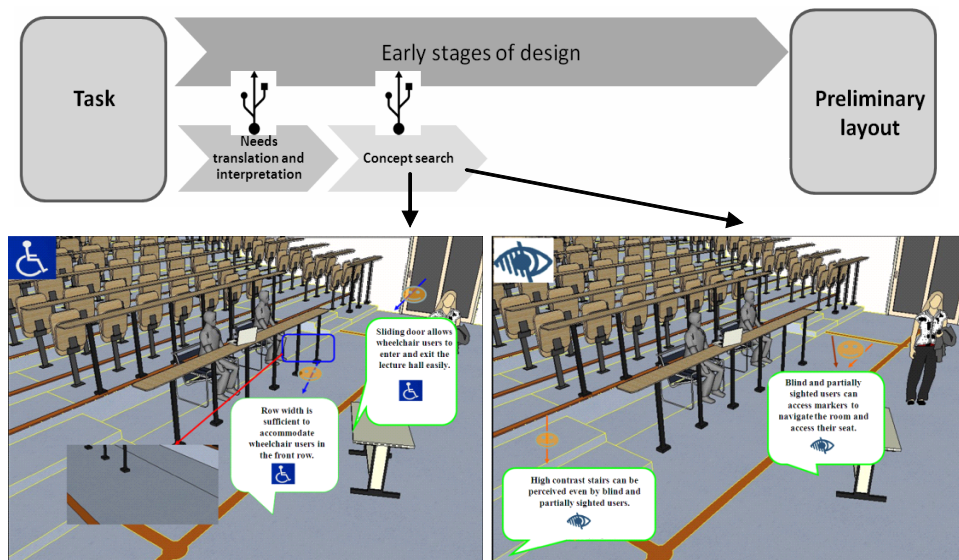
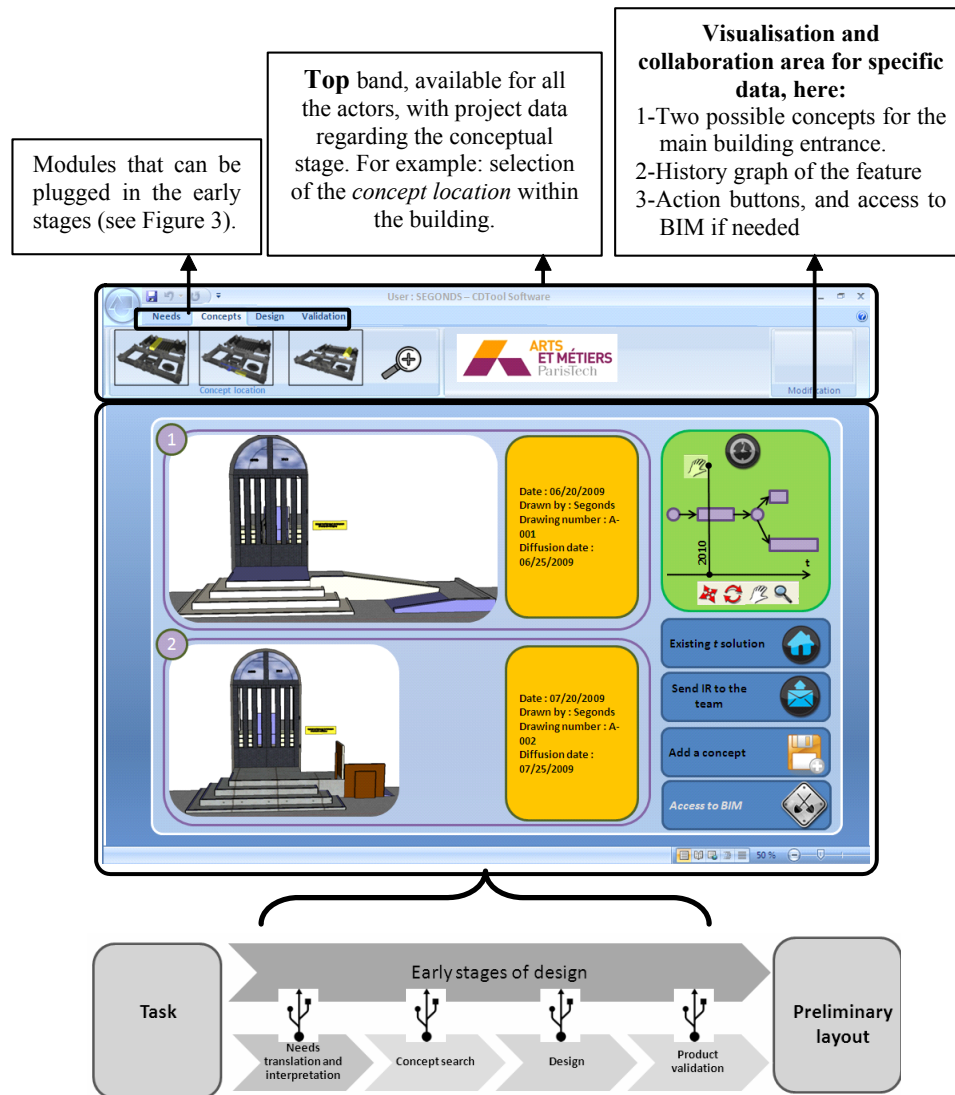


Figure 7 Mockup of a screen from our proposed software suite, and position in the global framework (see online version for colours)



Firms of architects can then propose concepts in response to the extended programme, which the client will choose from. If necessary, designers can highlight specific technical solutions with a bubble interface to explain the suggested alterations. Naturally, confidentiality of these contributions will have to be maintained between firms to ensure fairness in the process of selecting a contractor. For example, Figure 7 shows the main entrance of the building which is inaccessible to some users because of the stairs. The first concept developed by the architect is an approach ramp, and the second one is an elevator. Choosing between these two (or, indeed, rejecting them both) is partly the client's task. But it may also involve other professional to examine the feasibility of this concept with respect to redesign constraints (e.g., 'Are we allowed to build things at

street level?'). The 'design' and 'validation' thumbnails will allow the client to follow the project, thanks to IRs sent by the architect and/or the construction supervisor as work progresses. Moreover, these IRs can be presented to future users, who would be able to comment on the evolving solutions in participatory design, starting from the early stages of the process. From there, a collaborative area will allow stakeholders to check out the evolution of the building. A temporal cursor, located on the top right allows the user to view the time-wise evolutions of the building, and to view each important feature using the history graph notation (Renolen, 1996). All concepts are stored into a database, and all are available throughout the whole of the collaborative work.

The four buttons at the bottom right allow stakeholders and designers:

- To view the current solution under consideration, i.e., the latest CAD file, pictures, or historical reconstructions available at any given time and in any given thumbnail/stage of the process (needs, concepts, design or validation).
- To send IRs of the building to the whole team, via the internet. This function allows speedier collaboration and is useful when a consensus or design decision is urgently needed.
- To add concepts, if the architect has further solutions (or refinements of existing solutions) to suggest to the client.
- To access BIM modules relative to the solution under scrutiny. As seen in Section 3.4, this software suite must be linked to BIM software if the concept is sufficiently developed. In our example above, as the concept for the main entrance of the building has not been chosen so far, the BIM is not open and the text is in grey italic characters.

The connection of our tool with BIM modules is intended to assist the translation of design concepts into concrete, detailed design solutions. Interoperability between these two could, for example, use a standard data exchange format, e.g., standard for the exchange of product model data (STEP). STEP allows the capture and transfer of parameterised CAD models with geometric constraints, the transmission of behavioural information, and the description of operations used to construct them (Pratt and Anderson, 2001). This will allow seamless integration of computerised IRs following the progression of the architectural project in time – e.g., sketches, 3D concept models, plans, and finally, the physical building itself.

This global framework to help optimise client/contractor/user collaboration in the early stages of architectural rehabilitation can take into account the global evolution of the building. Annotated lightweight representations of the building allow various stakeholders to collaborate in order to define the most relevant solution to improve accessibility of a public building to its users.

5.4 Participatory evaluation of the tool concept

To assess the benefits and/or drawbacks of this tool, intended to assist collaborative work in architectural redesign, we carried out a survey to collect future users' impressions regarding the concept and recommendations for improvement in the future stages of software design.

Six people took part in the survey. Four of them were engineers, and two of them were ergonomists. All participants had experience in the field of architectural design (min = 2 years, median = 3.5 years, max = 26 years). The survey focused on:

- 1 the relevance of the 3D models used to illustrate design issues
- 2 solutions in a ‘before/after’ fashion (Figure 6)
- 3 the relevance of the overall tool architecture (see Figure 7).

Seven-point Likert scales were used to assess the relevance of the graphic scheme to illustrate accessibility issues and design solutions (see Figure 6), as well as the overall usefulness of the tool based on a description of its concept, as well as the usefulness, more specifically, of a function to track design changes. Open questions were used to collect information regarding the stakeholders which participants were expected to interact with using this tool, as well as regarding user propositions to improve the tool.

The graphic scheme was on average well received (min = 5, max = 6), scoring a median of 5 points out of 7. It was viewed as a clear and simple means to illustrate the accessibility issues and design solutions. These criteria were viewed as especially important since these elements need to be easily understood by all stakeholders in order to generate consensus.

This tool concept was viewed as useful for collaborative architectural design (min = 4, max = 6) with a median of 5 points out of 7 on the Likert scale. The main reason behind its usefulness was the possibility for the tool to be used as a means to put accessibility issues and design solutions ‘on the table’ for open discussion. This allows not just to foster consensus regarding design solutions, but to incite the client and contractors to act on accessibility issues that emerge, through this discussion, as being of crucial importance. By using this tool in the conceptual stages of redesign, specific issues can be integrated in the architectural programme and be a true focal point for design. These complex issues can then be examined with respect to design constraints (e.g., financial costs, time, low technical feasibility, etc.)

Finally, the survey allowed us to gather numerous suggestions to improve the tool in its future versions: e.g., support for *.dwg files – the native format in AutoCAD, a piece of software widely used by architecture professionals – to improve acceptability for architectural design agencies; a synoptic function for easy comparison of design solutions; expanding the focus of the tool from a room-based analysis to a wider focus on overall accessibility; and allowing designers to generate custom scenarios to describe accessibility issues in a more comprehensive, real-world manner.

6 Conclusions and future work

In this paper, we have highlighted some sources of complexity for user-centred redesign to assist the architectural rehabilitation of public buildings with a focus on PLM. To us, the need for increased focus on collaborative work using PLM in user-centred architectural redesign stems from:

- 1 a social and legal context specific to France, where demands for the rehabilitation of public buildings are liable to become very numerous in the near future
- 2 a specific social framework making integration of user-related data and participatory design notoriously difficult
- 3 an inability of design collectives to tackle accessibility issues in a structured fashion.

We have proposed the design of a prototype software platform to assist collaborative design in this context. Our future work will focus on a clearer characterisation of designer needs and practices in architectural redesign, and on evaluating the successive design iterations of this software suite.

Acknowledgements

The authors would like to thank Dr. Stéphanie Buisine and Pr. Lionel Roucoules for their valuable input in writing this paper.

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